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The Role of Energy Law and International Agreements in Technological Innovation in Nigeria and Other Selected Jurisdictions

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Abstract

Nigeria's efforts to diversify its energy mix and reduce dependence on fossil fuels have positioned renewable energy as a central pillar of the nation's energy policy. This article examines the role of law and international agreements in driving technological innovation in Nigeria's renewable energy sector. It provides an overview of the existing legal framework governing renewable energy in Nigeria, including the Electric Power Sector Reform Act, the National Renewable Energy and Energy Efficiency Policy, and other relevant laws and regulations. The article critically assesses the impact of these laws on technological innovation in the renewable energy sector, highlighting both the opportunities they present and the challenges they pose, including constraints on growth, development, and investment. The article also explores the impact of international ecological conferences and agreements, such as the Paris Agreement and the Sustainable Development Goals, on Nigeria's renewable energy landscape. Additionally, the discussion addresses the obstacles posed by current laws and policies, notably inadequate infrastructure, limited access to financing, and regulatory uncertainty. To place Nigeria's experience in context and identify transferable best practices, the article draws comparisons with selected jurisdictions that have successfully leveraged legal and policy frameworks to foster renewable energy innovation. The article concludes by identifying opportunities for law and policy reforms to support the growth of Nigeria's renewable energy sector, promote technological innovation, and contribute to sustainable development. The findings aim to guide legal and policy reforms that can catalyze technological advancement, attract investment, and align Nigeria's renewable energy transition with global sustainability commitments.

Keywords

Renewable energy; Nigeria; International agreements; Technological innovations; Sustainable development

Introduction

Apart from energy generation from fossil fuels, renewable energy has gained momentum in the Energy sector in Nigeria. The country's heavy reliance on fossil fuels, accounting for over 80% of electricity generation (Oyewo *et al*., 2018) and more than 90% of primary energy supply, has led to environmental degradation and persistent power supply challenges, prompting a growing interest in renewable energy as a sustainable alternative. Renewable energy is environmentally friendly, producing significantly lower carbon emissions. According to Statista, renewables contributed around 20.5% of Nigeria's total electricity generation in 2023 (Doris, 2025). The predominant sources of renewable energy in Nigeria are wind, solar, water, and biomass. These energy sources have not been sufficiently harnessed for domestic and industrial consumption, as research shows that current installed renewable capacity is estimated at under 4,000 MW (Mohammad *et al.*, 2024) far below the country's potential, exceeding 200,000 MW. Thus, Nigeria stands at a critical juncture in its energy development journey. The transition to renewable. Thus, Nigeria stands at a critical juncture in its energy development journey. The transition to renewable energy is not only essential for addressing energy access and climate change but also for fostering technological innovation and economic growth. Central to this transition is the role of law and international agreements, which provide the regulatory framework and incentives necessary to stimulate investment, guide development, and integrate renewable technologies into Nigeria's energy mix. These laws and international agreements, and the role they play in the country's energy landscape, will be discussed in the following paragraphs.

The role of the Electricity Act in Promoting or Impeding Technological Innovations

The Electricity Act has played a significant role in both promoting and impeding technological innovations. The following are some ways in which Nigerian laws have affected technological innovation:

1. The Act emphasizes the development and utilization of renewable energy sources. It encourages the integration of renewable energy technologies into the existing electricity grid system. Under the Act, the Nigerian Electricity Regulatory Commission (NERC) is mandated to promote the generation of electricity from renewable energy sources and may prescribe a minimum percentage of electricity to be generated from such sources by licensed generation companies. This is provided for in Section 142(1), thus "*The Commission shall promote the generation of electricity from renewable energy sources and may prescribe a minimum percentage of electricity to be generated from such sources by licensees involved in generation".* In line with Section 143(1), electricity generation license holders may also be required to fulfill renewable energy generation obligations as part of their licensing conditions. Electricity generation license holders are required to fulfil renewable energy generation obligations set by the Nigerian Electricity Regulatory Commission.

2. Tax Incentives: The National Renewable Energy and Energy Efficiency Policy (NREEEP) in Nigeria provides various incentives to promote renewable energy, including tax incentives for research and development (R&D) activities, which can stimulate technological innovations. These incentives may include tax credits,

exemptions, or deductions for companies engaging in R&D activities, encouraging investment in technology-driven sectors. The Electricity Act in Section 146(1) also introduces mechanisms to incentivize investments in renewable energy projects, by authorizing NERC to introduce feed-in tariff mechanisms, guaranteeing a fixed price for electricity generated from renewable sources and supplied to the grid. According to Bradbrook (1996), "The enactment of regulations and fiscal incentives is a variable tool enabling governments to control the size of the market for renewable energy and energy conservation products. Legal change can be introduced to stimulate the market and then withdrawn at a government's choosing if and when the government is satisfied that no further stimulation is required."

3. Intellectual Property Protection: While the Electricity Act, 2023 does not itself establish a new regime for intellectual property rights, it operates alongside Nigeria's broader Intellectual Property legal framework, particularly the Patents and Designs Act, Copyright Act, and Trademarks Act, to provide intellectual property protection through patents, copyrights, and trademarks. This protection encourages inventors, innovators, and creators to develop new technologies and ensures that their rights are safeguarded, promoting innovation and investment in technology-related sectors. Within its scope, the Act in Sections 63–65 establishes clear guidelines for the licensing, monitoring, and supervision of participants in the electricity market. These guidelines aim to prevent anti-competitive practices and ensure a level playing field for all industry players. By providing a framework for fair competition and regulation, the Act promotes transparency and accountability within the electricity sector.

4. The Electricity Act provides for public-private partnerships (PPPs) in various sectors, including technology. PPPs facilitate collaboration between government agencies, private enterprises, and research institutions, fostering innovation through joint efforts, resource sharing, and knowledge exchange.

Challenges and Impediments to Environmental Technologies

1. Regulatory Barriers: One way in which the above laws and policies may be perceived as impeding green technologies in Nigeria is through stringent regulatory processes and bureaucratic hurdles. The requirements for obtaining permits and certifications for green technology projects can be complex and time-consuming, leading to delays and increased costs for businesses. This can be a deterrent for companies seeking to invest in green technologies, particularly for smaller enterprises with limited resources. Meeting these standards may require additional investments in pollution control measures or environmental impact assessments, which can increase costs and create barriers to entry, particularly for smaller enterprises.

2. Limited Access to Funding and Project Financing: Limited access to funding and investment capital is a common challenge for technology startups in Nigeria. Despite efforts to promote funding opportunities, such as venture capital and Naguru investor networks. Many innovators struggle to secure adequate financial support to develop and scale their technological innovations.

3. Inadequate infrastructure and limited access to financing can also hinder the development and deployment of green technologies. The lack of reliable electricity and transportation infrastructure, for example, can impact the viability and scalability of certain green technology solutions. Additionally, the availability of affordable financing options specifically tailored towards green technology projects is often limited, which can pose a barrier to their widespread adoption.

4. Another challenge is the lack of clarity and consistency in environmental regulations. In Nigeria, there have been instances where the interpretation and enforcement of environmental laws have been inconsistent across different agencies and regions. This can create uncertainty for businesses and investors, making it difficult to plan and implement green technology projects effectively. In the same vein, Nigeria lacks a clear and coherent legal framework on alternative energy generation and supply that will ascertain the requirements and process for developing, financing, and implementing renewable energy source-based Electricity projects (RES-E projects) (Atsegbua and Daudu, 2019). Consequently, renewable energy projects are at best deployed as backup to traditional centralized grid electricity systems. This hinders the wide-scale deployment of renewable energy in Nigeria (Atsegbua and Daudu, 2019).

5. Land Use and Permitting Issues: Green technology projects, such as renewable energy installations or waste management facilities, often require suitable land for their implementation. However, land acquisition and permitting processes in Nigeria can be complex and time-consuming. Delays in obtaining land rights and permits can impede the development of green technology projects and discourage potential investors.

6. Inadequate Incentives: While environmental laws provide a regulatory framework, the availability of financial incentives and support mechanisms for green technologies in Nigeria is still limited. The lack of targeted incentives, such as tax breaks, grants, or subsidies, can hinder the economic viability of green technology projects and slow down their adoption and deployment.

7. Limited Public Awareness of the Potential of Renewable Energy and Electricity: The majority of Nigerians are still accustomed to using traditional energy sources, and there is limited public awareness regarding the significant potential of renewable energy projects in Nigeria. Due to this lack of awareness, there is a lack of initiatives aimed at harnessing the vast potential of renewable energy. This information gap creates a void market and leads to a higher perception of risk for potential renewable energy projects.

International Agreements and Cooperation

The role of international agreements and cooperation in shaping Nigeria's environmental legal landscape in relation to technological innovation. Fundamentally, energy could be referred to as the cornerstone for the progress of most nations, as a lack of unswerving energy sources perpetuates poverty and impedes economic development. Therefore, discussions on the adoption of low-carbon energy sources have been a recurring topic in international ecological conferences hosted by organizations like the United Nations. These discussions have led to the following outcomes:

1. The increase in global awareness about the importance of transitioning to low-carbon energy sources as a means to combat climate change and reduce greenhouse gas emissions. These have helped to highlight the urgency of addressing the environmental impacts associated with conventional energy sources.
2. The development of policies and frameworks at national and international levels. These have provided a platform for countries to share best practices, exchange ideas, and learn from successful case studies, ultimately leading to the formulation and implementation of policies that promote the adoption of low-carbon energy sources.
3. The discussions have facilitated international cooperation and collaboration among countries, organizations, and stakeholders. These have created opportunities for partnerships, knowledge sharing, and enabling countries to collectively work towards a sustainable energy future.
4. The discussions have spurred innovation in low-carbon energy technologies. It has encouraged research and development efforts, investments, and technological advancements in renewable energy sources, making them more accessible, efficient, and cost-effective.
5. There have evolved various commitments and agreements have evolved among countries to increase the share of renewable energy in their energy mix and reduce greenhouse gas emissions. International agreements such as the Paris Agreement have been influenced by these discussions, setting targets and goals for countries to transition towards low-carbon energy sources.
6. The transformation of energy markets, with an increasing focus on renewable energy sources. They have influenced investor interests, financial institutions, and businesses to shift towards sustainable and low-carbon energy investments, driving market growth and creating opportunities for renewable energy technologies. International agreements and cooperation have also played a significant role in shaping Nigeria's environmental landscape, particularly concerning technological innovation.
7. International agreements often include provisions for technology transfer, which involve the sharing of environmentally sound technologies and know-how between countries. Through these agreements, Nigeria can access innovative technologies related to renewable energy, waste management, pollution control, and other sustainable environmental practices. This facilitates the adoption and implementation of advanced technologies within the country (Nwokolo, Meyer and Ahia, 2023).
8. International agreements often involve the development and adoption of common standards and best practices related to environmental technologies. These standards help ensure that innovation in Nigeria aligns with global environmental goals and facilitates international trade and cooperation. Harmonization of standards will enable Nigeria to integrate with international markets and attract investments in environmentally friendly technologies.
9. Policy Alignment: International agreements set global goals and targets for environmental protection and sustainable development. Nigeria's participation in these agreements encourages alignment of its domestic policies and laws with international standards. This creates a conducive environment for technological innovation by providing a clear regulatory framework and promoting consistency in environmental practices.
10. International agreements and cooperation can offer financial assistance and funding mechanisms to support technological innovation in Nigeria's environmental sector. This can include grants, loans, and investment funds targeting clean technologies

and sustainable projects. Collaboration among nations enables the pooling of resources and shared financial responsibility for implementing large-scale climate initiatives, thereby increasing the feasibility for countries with limited resources to take substantial action (Nwokolo, Meyer and Ahia, 2023). Financial support helps to overcome barriers to technology adoption and promotes the development and deployment of innovative environmental solutions.

Renewable Energy in China

As of today, China produces 31% of global renewable electricity, followed by the United States (11%), Brazil (6.4%), Canada (5.4%), and India (3.9%) (IRENA-IRENASTAT, 2024). China has emerged as the global leader in electricity production from renewable energy sources, surpassing other countries by a significant margin. Its renewable energy sector is experiencing rapid growth, outpacing its fossil fuels and nuclear power capacity. It is projected to contribute a significant portion of global renewable capacity growth, reaching approximately 43% (Isabel, 2024). China's total renewable energy capacity exceeded 1,000 GW in 2021, accounting for 43.5 per cent of the country's total power generation capacity, 10.2 percentage points higher than in 2015. The country aims to have 80 per cent of its total energy mix come from non-fossil fuel sources by 2060, and achieve a combined 1,200 GW of solar and wind capacity by 2030 (Yujie, 2022). China currently has the world's largest installed capacity of hydro, solar, and wind power.

As of 2019, renewable sources provided 26% of its electricity generation, with most of the remainder provided by coal power plants (China Energy Portal, 2020). By the beginning of 2020, approximately 40% of China's overall installed electric power capacity was made up of renewable energy sources, while renewable energy accounted for 26% of the total power generated. However, in 2021, the proportion of renewable energy in the total power generated increased to 29.4%. Thus, between 2019 and 2024, China is projected to account for 40% of global renewable capacity expansion, driven by improved system integration, lower curtailment rates, and enhanced competitiveness of both solar PV and onshore wind. During the same period, China is forecast to account for almost half of global distributed PV growth, overtaking the EU to become the world leader in installed capacity by 2021(IEA50, 2024).

As of the first quarter of 2024, China has achieved the highest capacity of utility-scale solar power globally, totaling 228 GW. Additionally, China has commenced operations at the world's largest hybrid solar-hydro power plant, Kela, located on the Tibetan plateau. This facility is capable of generating 2 billion kilowatt-hours of electricity annually, sufficient to meet the energy needs of over 700,000 households. It is only the first phase of a massive clean energy project in the Yalong River basin. The installation has a 20GW capacity now and is expected to reach about 50GW by 2030 (Hawkins and Cheung, 2023). The country's combined onshore and offshore wind capacity has surpassed 310GW, double its 2017 level. China is on track to double its wind and solar power capacity and produce 1,200 gigawatts of energy by this year, reaching its 2030 goal five years ahead of time (Hawkins and Cheung, 2023). The share of renewables in China's total power generation is expected to increase to 36% before the end of 2025 (Sam, 2023) and the nation aims to achieve carbon neutrality before 2060 and peak emissions before 2030 (IEA50, 2024).

This demonstrates China's commitment to transitioning towards cleaner and more sustainable energy sources. The country leads the world in renewable energy production figures and is the largest producer of wind and solar energy. China has also become a major investor in renewable energy, both domestically and internationally (Chia, 2022). The country is investing in energy storage and green technologies to ensure a secure and sustainable energy future, exploring innovative technologies such as hydrogen and carbon capture to further reduce emissions from its industrial facilities. China is also set to lead global growth in biofuel production, with increasing investments in production capacity and the rollout of ethanol blending in several provinces (IEA50, 2024). China's clean energy innovation has been driven by economic opportunism, recognizing the immense economic potential in green energy industries (Chia, 2022).

This immense capacity has contributed to driving down prices of renewable systems worldwide, making them more accessible for poorer countries, as it has now become a major investor in renewable energy both domestically and internationally. China plays a significant role in technology transfer in the clean energy sector to developing countries. Through its investments, collaborations, and research and development efforts, China has become a leading source of clean energy technology for other nations (Lewis, 2023).

Despite China's meticulous planning, the energy transition faces significant challenges. Recent extreme weather events, such as heatwaves and droughts, have negatively impacted hydropower stations, leading to power shortages and disrupting industrial operations, highlighting the vulnerability of certain renewable energy sources to climate change. The outdated electricity grid and limited technology for transferring energy between different regions further contribute to the uncertainties. This limitation hampers the efficient distribution and integration of renewable energy sources (Chunping, 2022). The Kela plant, situated in the less densely populated western region of China, is responsible for generating more than three-quarters of the country's coal, wind, and solar power. However, the majority of energy consumption occurs in the eastern part of the country. The long-distance transportation of energy across thousands of miles results in inefficiencies and adds complexity to the energy transition process. Despite its leadership in renewable energy, China still has high coal demand and production capacity. Currently, one out of every four tons of coal used globally is burned to produce electricity in China (IEA50, 2024). More coal power was approved in the first three months of 2023 than in the whole of 2021.

“China is making strides”, said Martin Weil, a researcher at Global Energy Monitor and an author of the report. “But with coal still holding sway as the dominant power source, the country needs bolder advancements in energy storage and green technologies for a secure energy future” (Hawkins and Cheung, 2023). However, the government is actively pushing for emissions reductions and improved air quality by transitioning to natural gas in the industrial and residential sectors.

Carbon Capture Storage in China

China attaches great importance to the development of Carbon Capture, Utilization and Storage (CUS) technology. China's efforts to address climate change are evident in its Scientific and Technological Actions on Climate Change. One of the crucial tasks

outlined in this plan is the advancement of technologies that capture, utilize, and store CO_2. By focusing on the research, development, and implementation of Carbon Capture, Utilization, and Storage (CCUS) technology, China aims to have a strategic technical solution to control greenhouse gas emissions in the future. The Ministry of Science and Technology (MOST) in China has been actively supporting the theoretical studies, development of key technologies, establishment of demonstration plants, and formulation of strategies related to CO_2 capture, transport, utilization, and storage. These efforts aim to foster technological innovation, reduce energy consumption and costs, and explore potential applications for CO_2 utilization (The Ministry of Science and Technology of China, 2010). CCUS was initially developed in China before 2006, with the China Union Coal ECBM (Enhanced Coalbed Methane Recovery) project in Qinshui, Shanxi, becoming the first project in China to utilize CO_2 (Wang *et al*., 2023). The number of CCUS projects in China has been increasing over the years. In the early stages (2006-2010), one new CCUS project was added each year.

From 2010 to 2016, the development of CCUS projects accelerated, with an average of 3 new projects per year. Large-scale projects are the development trend, with 70% of proposed or established projects aiming for emission reductions above 1 million tons. The number of new CCUS projects is expected to grow faster or at least maintain the previous growth rate (Wang *et al*., 2023). By the end of 2020, China's CCUS emission reduction was 3.298 million tons. The emission reduction potential of CCUS is projected in two ways: the growth of the number of CCUS projects and the growth of CCUS emission reduction (Wang *et al.*, 2023). In the first half of 2023, China's advancements in carbon capture, utilization, and storage (CCUS) were underscored by the China Petroleum and Chemical Corporation's launch of the nation's inaugural integrated megaton-scale CCUS project in Shandong. This initiative represents a significant milestone in the development of CCUS technologies in China (Yang, 2023).

China National Offshore Oil Company (CNOOC) launched the first offshore CO_2 storage project in the Pearl River Mouth Basin, southwest of Hong Kong. This project aims to inject CO_2 deep underground for long-term storage. Huaneng Group developed the first commercial-scale carbon capture facility at an NGCC (Natural Gas Combined Cycle) facility in Hainan Island. This pilot project aims to capture 2,000 tonnes of CO_2 per year using post-combustion capture technology (Yang, 2023). China National Building Material initiated the construction of the world's largest oxyfuel CCUS project in the cement industry. This project, located in Qinzhou, Shandong, aims to capture 200,000 tonnes of CO_2 per year.

While policy and regulatory frameworks for CCUS in China are still developing, the country's determination to understand and implement this technology to achieve carbon neutrality is evident. President Xi Jinping's emphasis on transitioning to dual control over the maximum volume and intensity of carbon emissions signals the importance of CCUS in China's future policy regime. Therefore, it is reasonable to assume that this CCUS momentum will continue in China for the foreseeable future.

Renewable Energy in the United States of America

The United States possesses abundant natural resources, particularly in the realm of renewable energy, which are sufficient to produce over 100 times the quantity of electricity consumed by Americans annually. Fossil fuels comprise roughly 79% of the United States' energy production, with renewable sources contributing 13.1% and nuclear energy at 8.0%. Significantly, in 2019, renewable energy sources surpassed coal in their contribution to the nation's energy supply, a trend that has continued through 2022. While wind and solar power are the most rapidly expanding renewable sources, they currently only contribute 6% to the overall energy consumption in the United States. Over 13 GW of wind capacity was installed in the U.S. in 2021 and over 16 GW in 2020 (US DOE, 2022). The US manufactured 1% of PV cells and 2.7% of PV modules globally in 2021 (IEA, 2022). Solar capacity has grown at an average of 24% annually over the last decade. In 2022, the total installed capacity reached nearly 150 GW, with solar energy contributing the most significant increase in generating capacity to the grid over the past four years. It accounted for 54% of new generating capacity in Q1 of 2023. Nearly 30 GW of solar installations are projected to take place in 2023 (SEIA, 2023).

The US Department of Energy's SunShot Initiative aims to reduce the price of solar energy to 50% by 2030, which is projected to lead to 33% of U.S. electricity demand being met by solar and an 18% decrease in electricity sector greenhouse gas emissions by 2050 (NREL, 2023).

In the US, there are various laws, initiatives, and policies that promote and encourage technologies for clean energy. This includes the Energy Policy Act of 2005, which established the Renewable Fuel Standard (RFS), requiring a certain volume of renewable fuels, such as ethanol and biodiesel, to be blended into transportation fuels. The American Recovery and Reinvestment Act of 2009 provides significant funding for renewable energy projects, including grants, loan guarantees, and tax incentives, to stimulate the growth of the renewable energy industry. The Energy Independence and Security Act of 2007, which increased the Renewable Fuel Standard, set new energy efficiency standards for appliances and buildings, and promoted the development of advanced biofuels and renewable energy technologies. The Clean Power Plan, although not a law, was a regulation introduced by the Environmental Protection Agency (EPA) in 2015. It aimed to reduce carbon emissions from power plants and encouraged the use of renewable energy sources. The Investment Tax Credit (ITC) and Production Tax Credit (PTC) are federal tax incentives that provide financial support for renewable energy projects. The ITC offers a tax credit for solar energy systems and other qualifying renewable energy technologies, while the PTC provides a tax credit for electricity generated from renewable sources such as wind, biomass, and geothermal (Bureau of Land Management, 2024; Library of Congress, 2024; US Department of Energy, 2024).

Laws Promoting Carbon Capture and Storage in the US

Carbon Capture and Storage (CCS) in the USA is primarily focused on providing financial support and incentives for the development and implementation of CCS technologies. While there are no specific federal environmental regulations for CCS projects, various federal laws and regulations enable federal agencies to influence CCS efforts in

coordination with state regulatory agencies. Companies that capture and store CO_2 are eligible for the section 45Q federal tax credit. The federal government has provided significant financial support for CCS research and development. Annual appropriations for CCS research and related programs have totaled billions of dollars over the years. The American Recovery and Reinvestment Act of 2009 and the 2021 Infrastructure Investment and Jobs Act have also provided substantial funding for CCS programmes. The reconciliation act of 2022 expanded the section 45Q credit significantly (Carbon Capture and Storage in the United States Congressional Budget Office).

Assessing the Effectiveness of Environmental Governmental and Technological Innovations in Nigeria

Nigeria has significant potential for clean energy sources like solar, wind, and hydropower, but the adoption and use of clean energy technologies have been limited so far. Francesco La Camera, Director of the International Renewables Energy Agency (IRENA), said: "Nigeria can provide sustainable energy for all its citizens in a cost-effective manner by using its abundant, untapped renewables. Nigeria has a unique opportunity to develop a sustainable energy system based on renewables that supports socioeconomic recovery and development, while addressing climate challenges and accomplishing energy security." Nigeria's renewables report shows that renewable energy sources can meet nearly 60% of Nigeria's energy demand in 2050. This could cut the country's demand for oil by 65% and natural gas by 40%, and could see renewables account for 47% of total energy demand by 2030, and 57% by 2040, impressive figures for a country without an established history of renewable investment. The adoption of renewable energy in Nigeria has a relatively short history, but it is not entirely true that renewables have not been utilized in the country. Hydropower has been a significant source of electricity in Nigeria since the 1960s, with the Kanji and Jebba Dams accounting for about half of the country's power sources. Hydropower is the second-largest source of electricity in Nigeria after thermal power (Modor Intelligence, 2024). However, in recent years, the focus has shifted towards gas-powered stations for electricity generation, mainly due to issues such as poor management, corruption, and unstable gas supplies.

Currently, out of the 23 operational power plants in Nigeria, only three are hydro plants, while the rest are gas plants. The last hydropower plant was built 38 years ago. However, with the increasing global concern about climate change and the need to reduce carbon emissions, the Federal Government of Nigeria has started diversifying its energy sources to include renewables. One of the initiatives taken by the government is the establishment of new large-scale hydropower plants in areas of the country with identified hydro potential for electricity generation. The Federal Ministry of Water Resources (FMWR) has conducted studies on completed and ongoing dam projects for hydropower, including Gurara, Oyan, IKere Gorge, Bakolori, Dadin Kowa, Tiga, Kiri, Jibiya, Challawa Gorge, Owena, Doma, Waya, Mgowo, Zobe, Kampe, Kashimbilla, Ogwashiku, Zungeru, and Mambilla (The World Bank, 2023).

Meanwhile, the northern part of the country's average wind speeds at 10 m above sea level average between 2.1 m/second and 8 m/s, easily fast enough to support wind

turbines. The country's Federal Ministry of Power has also mapped the movement of offshore wind to find wind energy potential over Nigerian waters (Smruthi, 2023).

Solar energy has gained prominence in terms of investment and adoption. Nigeria is located around the equator, within a high sunshine belt, which means that solar radiation is fairly distributed throughout the country. The annual daily average of total solar radiation in Nigeria ranges from about 12.6 MJ/m^2/day (3.5kWh/m^2/day) in the southern coastal regions to about 25.2 MJ/m^2/day (7.0kWh/m^2/day) in the far north (Ogheneruona, 2021). Solar resources are highest in the northern regions of Nigeria, which are arid with high temperatures and low rainfall. In contrast, the southern regions have less potential for solar energy due to cloudiness and longer rainy seasons. The government and private sector are increasingly recognizing the importance of solar energy and are taking steps to promote its development.

An example of large-scale solar investment is the agreement signed between the Nigerian government and Sun Africa to install solar energy production systems in poorly served localities, with a loan of USD 1.5 billion from Exim Bank. The report shows that 60% of solar energy adopters in Kano city, Nigeria, installed their solar system between 2015 and 2016, which reveals that there is an increase in the adoption of solar PV by Kano residents. Over 50% of respondents who have adopted solar PV were residents in unplanned neighbourhoods of the city (Barau, Abubakar and Kiyawa, 2020).

Compared to the value of wind accessible in Nigeria, wind energy development is still at an early stage in Nigeria. Its development has not experienced significant progress in recent years. Analysis of wind energy resources in various locations in Nigeria was investigated from 1951 to 1975 at 10 m. The northern part produced the highest wind, especially in Nguru and Sokoto, while the southern region produced less wind, from 1.40 to 3 m/s (Ojosu and Salawu, 1990). Nigeria has abundant biomass resources, including forest residue, agricultural waste, animal waste, and municipal waste. In present-day Nigeria, it is mostly the rural dwellers who utilize biomass to meet their energy needs in Nigeria. Forest residue alone has an estimated energy potential of about 8.68 Mtoe (363 PJ) from approximately 19 million tonnes of biomass resources [Biomass Resources in Nigeria and the Conversion Pathways] (Ugwu *et al*., 2022).

Wood fuels, such as firewood and charcoal, are widely used in Nigeria, especially in rural areas. Wood fuels account for over 90% of the total energy consumption in the country and about 99% in rural areas (Benti *et al.*, 2021). Animal dung, particularly cow dung, is commonly used as biomass fuel in Nigeria. It is primarily used in the form of dung cakes for cooking purposes. According to the report by the National Agricultural Sample Survey (NASS), which was done between 2010 and 2011, there are about twelve major crops for bioenergy production in Nigeria, such as maize, cowpea, cotton, cassava, cocoyam, groundnut, melon, soya beans, millet, rice, yam, and guinea corn (Ugwu *et al*., 2022). Nigerian National Petroleum Corporation (NNPC) currently has several planned infrastructure projects as it undergoes a transition to renewable energy. There are opportunities for investment in renewable energy projects, including (ITA, 2023):

1. Sugarcane fuel ethanol
2. Cassava fuel Ethanol
3. Oil Palm biodiesel in Calabar (Cross River State)

4. Solar and wind energy power generation
5. Emission reduction

Conclusion

Nigeria's renewable energy future hinges on effectively harmonizing its legal frameworks with international sustainability commitments to address key challenges such as regulatory barriers, infrastructure deficits, and limited access to finance. Strengthening enforcement mechanisms, increasing funding for renewable energy research, and clarifying institutional roles are essential steps to foster technological innovation and sector development. Lessons drawn from other jurisdictions demonstrate the importance of clear policies, robust regulations, and supportive investment environments, offering valuable guidance for Nigeria's reform efforts. Moreover, international partnerships that emphasize technology transfer and capacity-building will be vital to achieving sustainable growth. By fully harnessing the potential of renewable energy and leveraging the combined power of law and international agreements, Nigeria can advance sustainable development, enhance energy security, and stimulate economic growth — all while contributing meaningfully to global climate change mitigation goals. Urgent legal and policy reforms are therefore critical if Nigeria is to meet its global sustainability commitments and secure a resilient energy future.

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Authors' Declarations and Essential Ethical Compliances

Authors' Contributions (in accordance with ICMJE criteria for authorship)

Contribution	*Author 1*	*Author 2*
Conceived and designed the research or analysis	No	No
Collected the data	No	No
Contributed to data analysis & interpretation	Yes	Yes
Wrote the article/paper	Yes	No
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Editing of the article/paper	No	Yes
Supervision	No	Yes
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